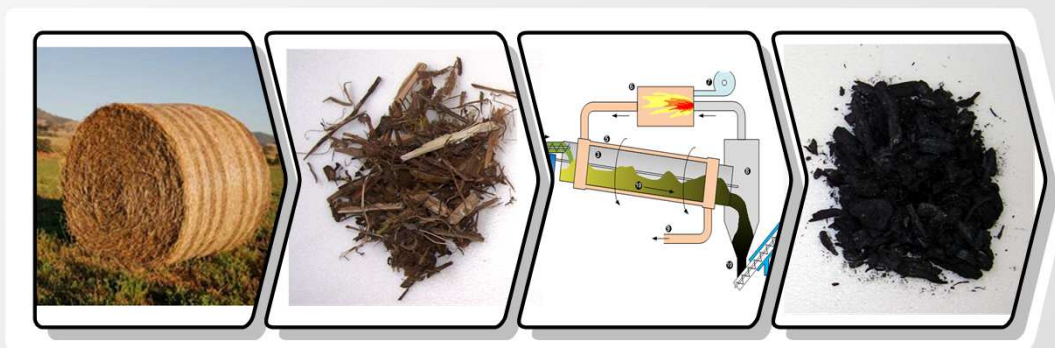

Biomass pyrolysis and biochar characterization

Ronsse, F., Dickinson, D., Nachenius, R. & Prins, W.

*Department Of Biosystems Engineering,
Faculty of Bioscience Engineering, Ghent University (Belgium)*



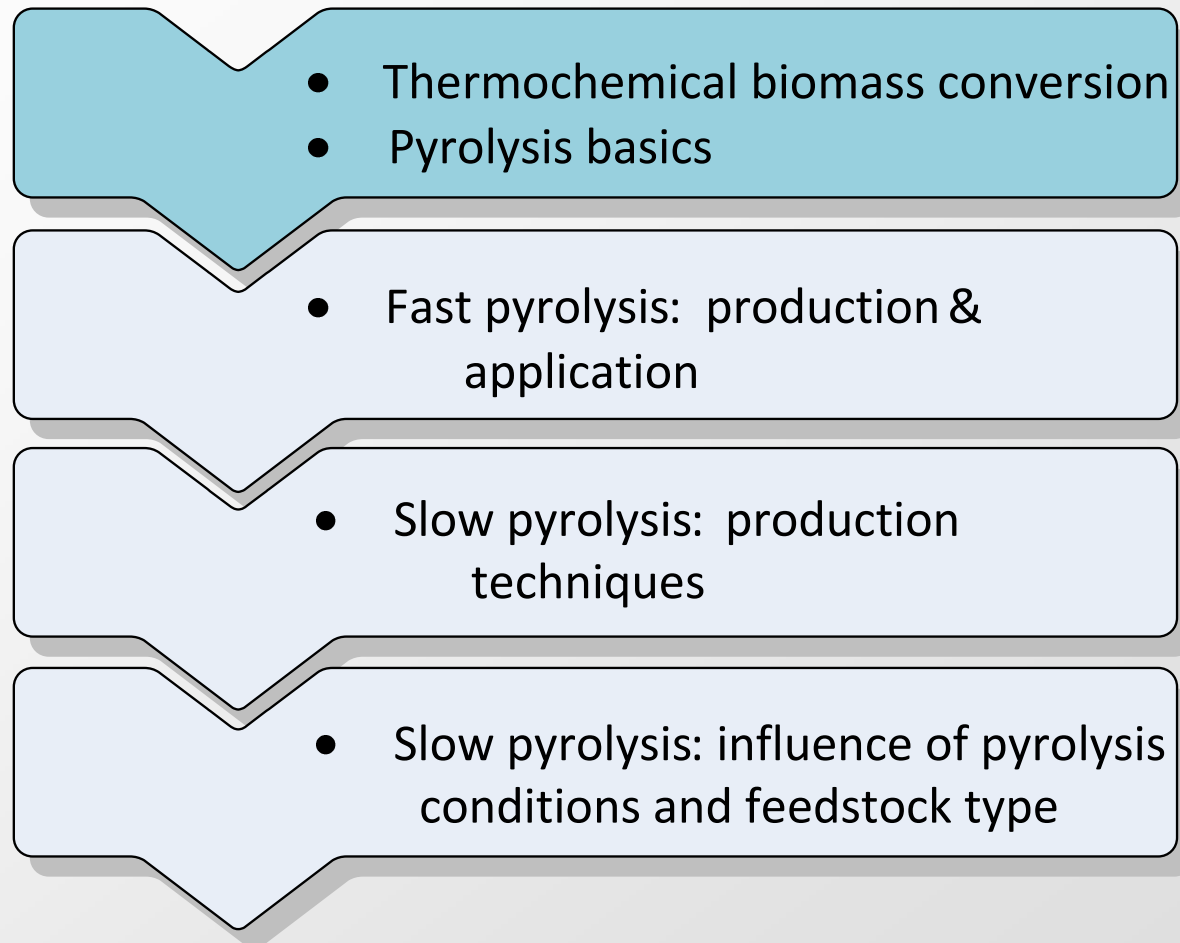
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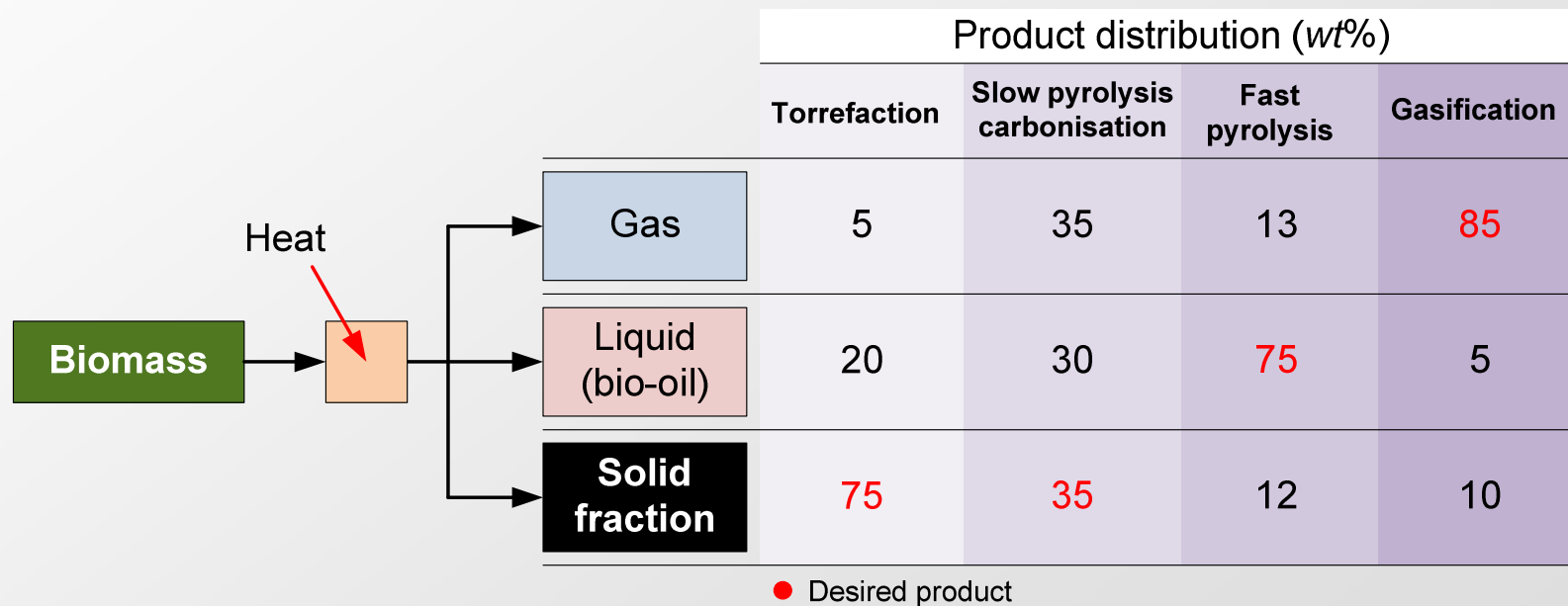
- Outline of the presentation



Pyrolysis: basics

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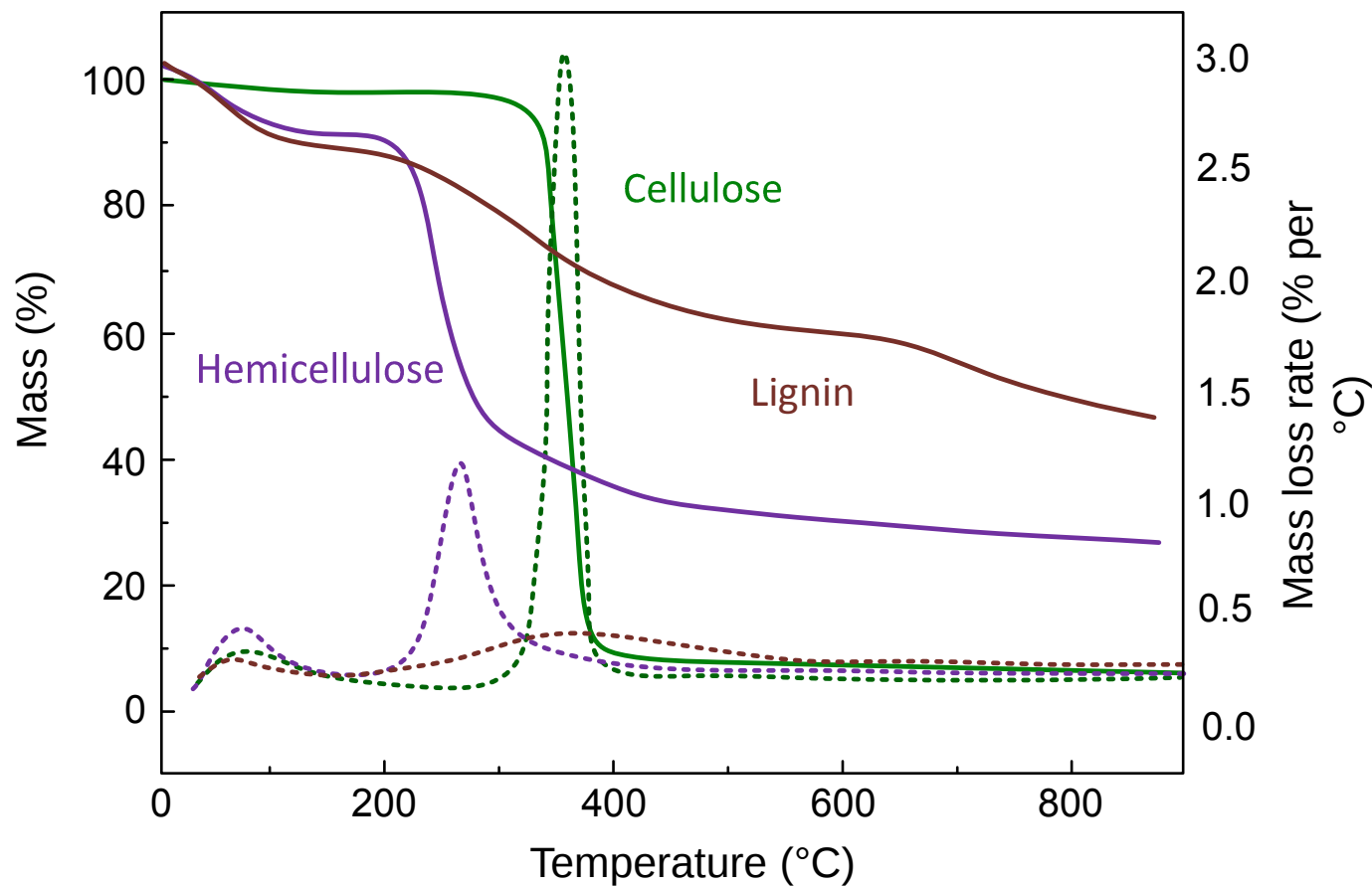
- The decomposition of biomass by heating in an oxygen-free or oxygen-limited environment
- Results in the production of three phases: **gas**, condensable vapours (leading up to **bio-oil**) and **char** ($\rightarrow$ *biochar*)
- Fast reactions, but in practice heat and mass transfer limitations occur affecting product distribution



Pyrolysis: basics

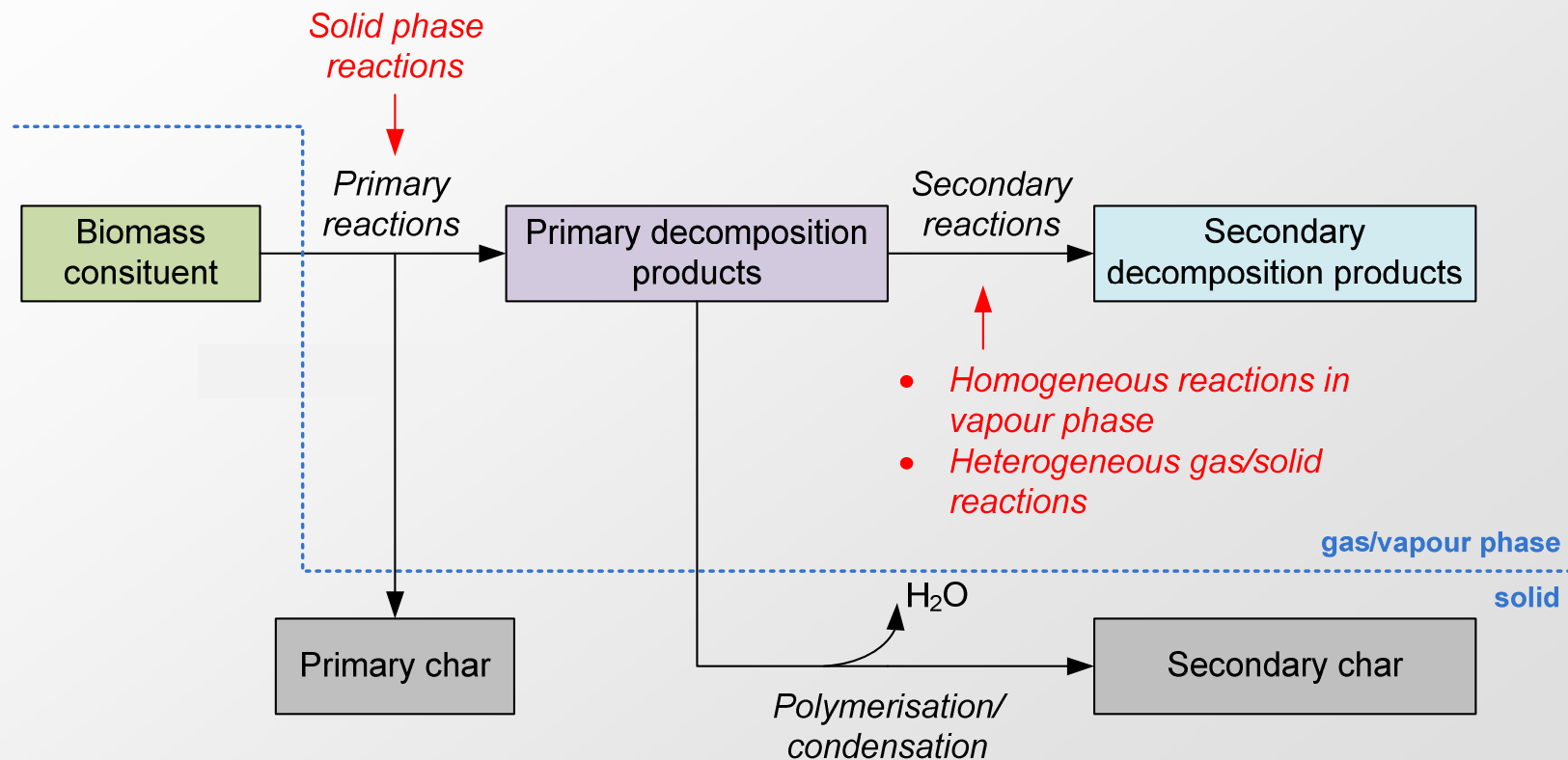
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- Biomass is composed out of cellulose, hemicellulose and lignin (+ extractives/ash)
- Different biomass constituents have different pyrolysis behaviour
- i.e. TGA



Pyrolysis: basics

- How is char formed during pyrolysis (chemically) ?
 - Distinction between primary and secondary char
 - Generalized scheme



- Above scheme is not applicable to hydrothermal processes.

Fast pyrolysis

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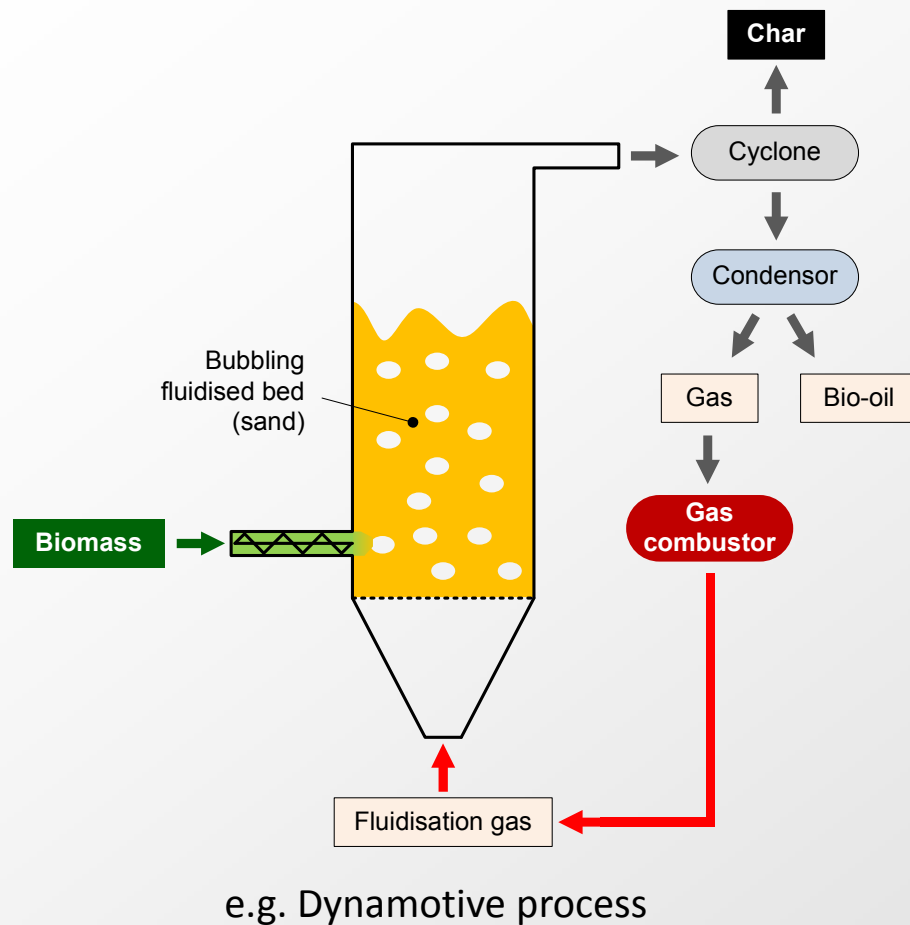
- Reaction conditions
 - Dry feedstock (< 12 wt% moisture)
 - Biomass heating up to 500°C in 1 - 2 s
 - Small biomass particles (1 a 2 mm)
 - Vapour residence time of 1 s (max. 5 s)
- Pyrolysis reactor configurations
 - 'Bubbling' fluidised beds
 - Circulating fluidised beds (CFB)
 - Rotating cone
 - Auger reactor
 - Others: ablative reactor, vacuum pyrolysis reactor



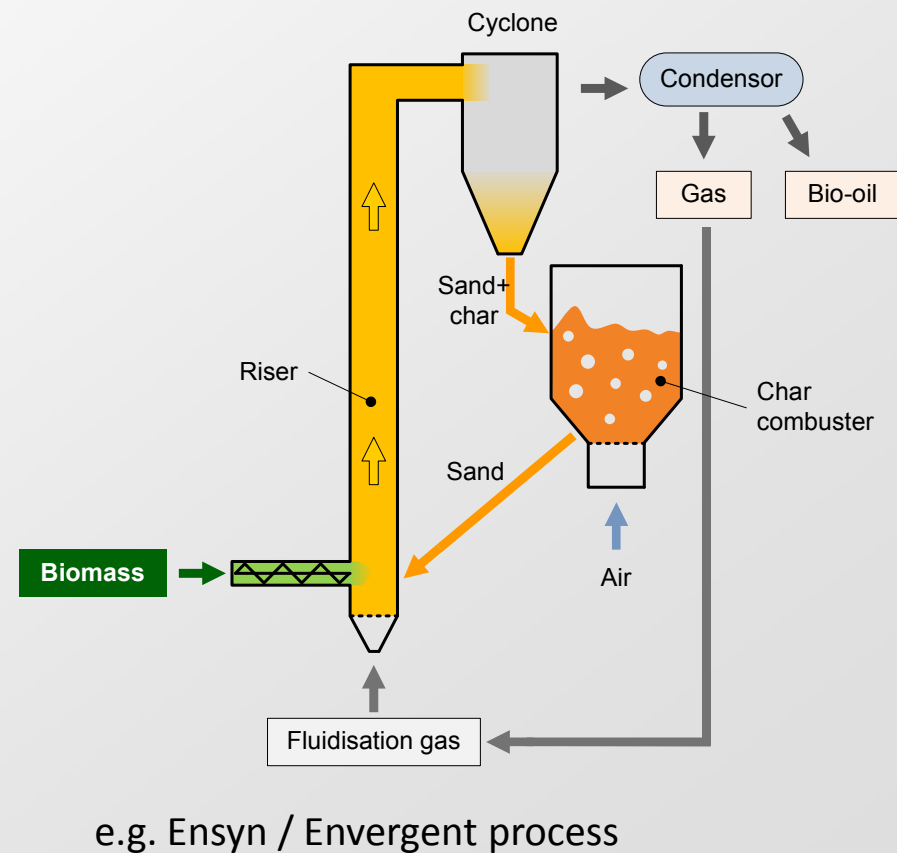
Fast pyrolysis

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- Bubbling fluidised bed



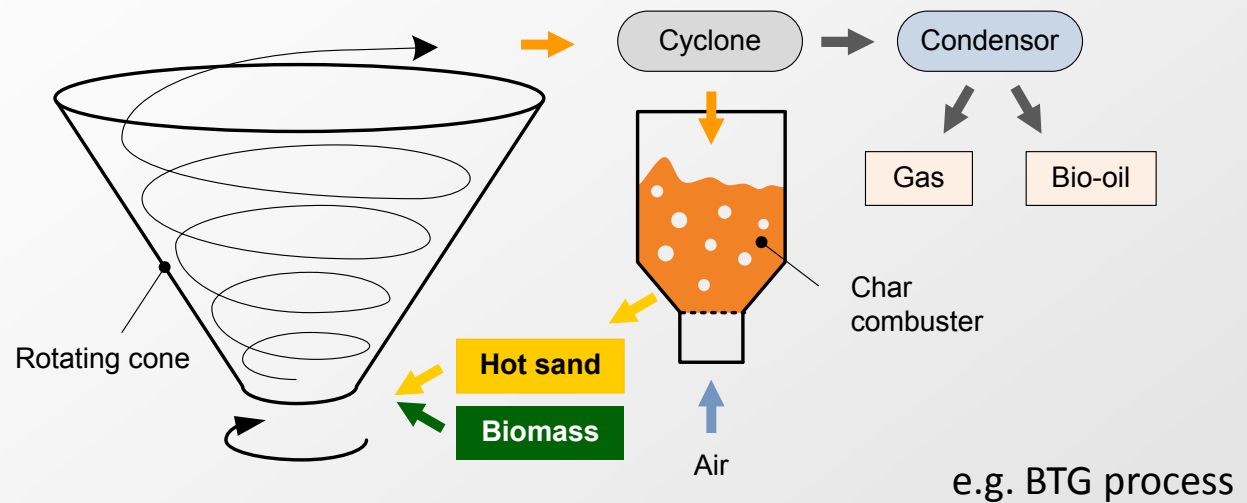
- Circulating fluidised bed



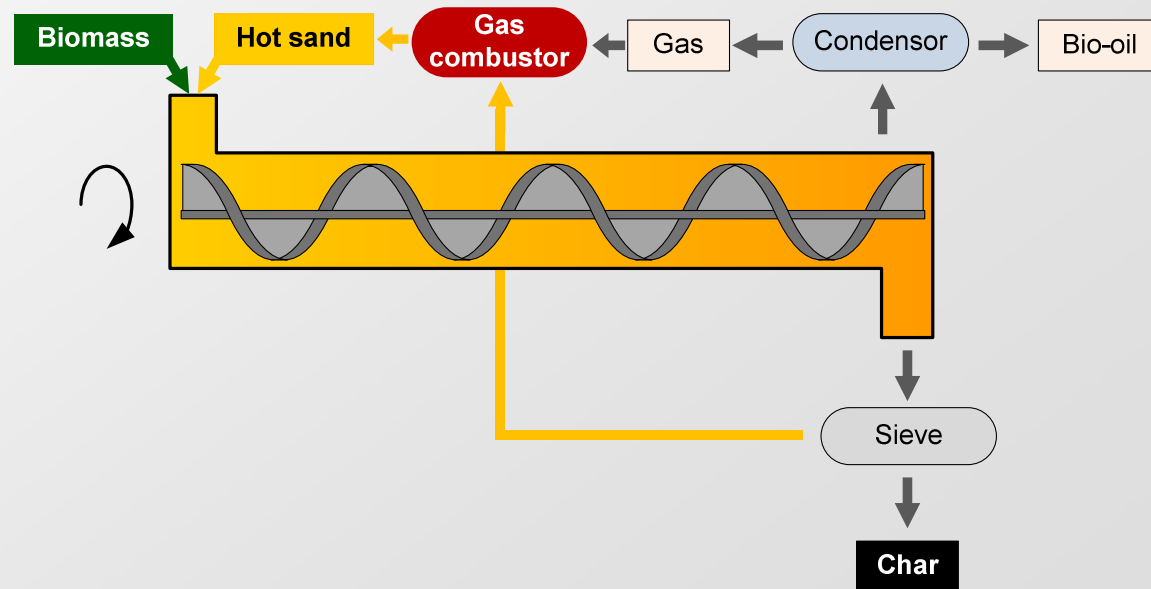
Fast pyrolysis

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- Rotating cone reactor



- Auger or screw reactor
 - Single or twin screw configurations

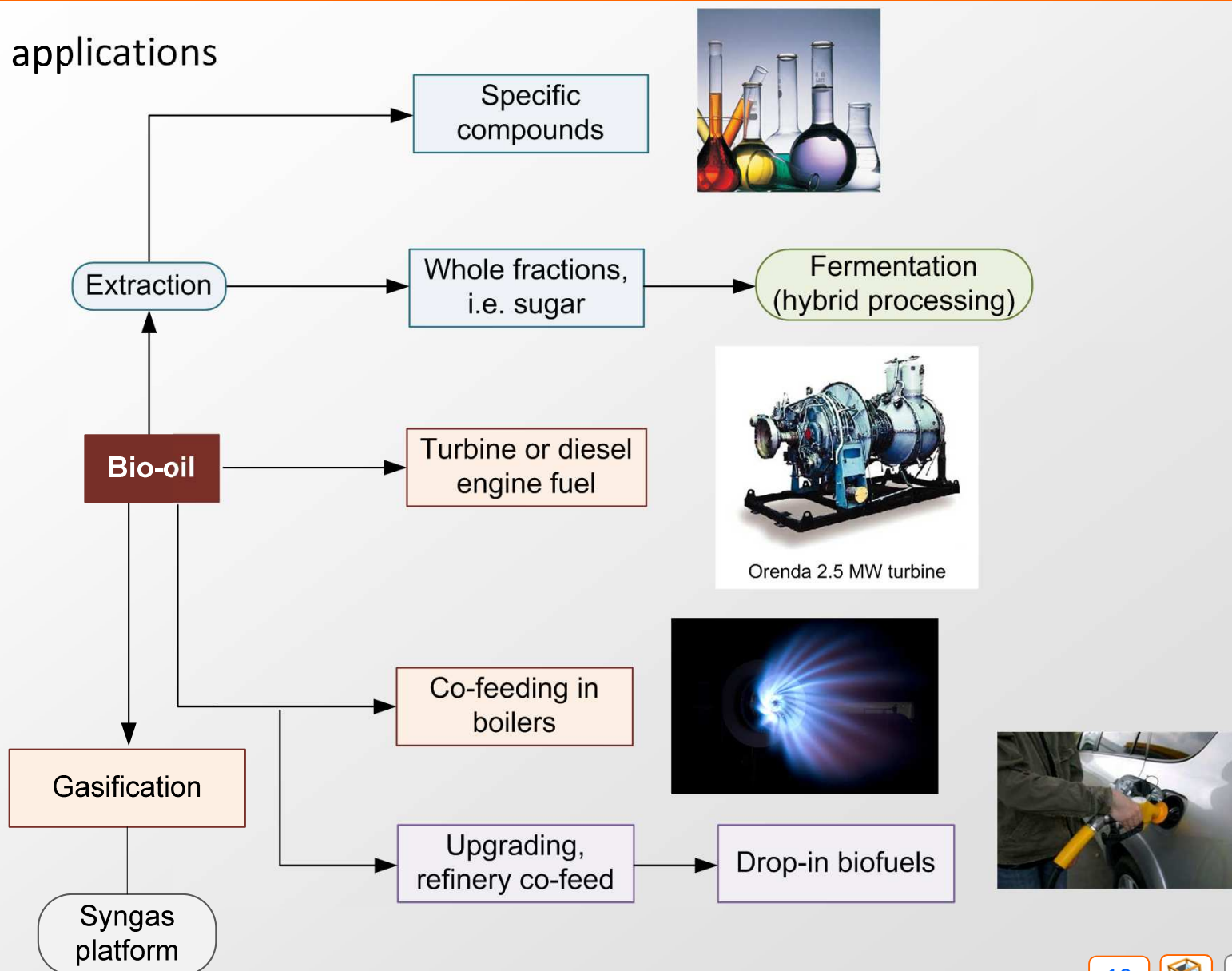


- Bio-oil properties
 - Combustible, HHV ~ 18 MJ/kg
 - Rich in oxygenated compounds
 - 10 to 15 wt% water
 - Highly corrosive, pH ~ 2
 - Not distillable
 - Unstable (ageing = polymerisation of bio-oil compounds)
 - Immiscible with hydrocarbons
 - Low cetane number (10 ~ 25)

Source: Piskorz, J., et al. In Pyrolysis Oils from Biomass, Soltes, E. J., Milne, T. A., Eds., ACS Symposium Series 376, 1988.	White Spruce	Poplar
Moisture content, wt%	7.0	3.3
Particle size, µm (max)	1000	590
Temperature	500	497
Apparent residence time	0.65	0.48
Product Yields, wt %, m.f.		
→ Water	11.6	12.2
Gas	7.8	10.8
Bio-char	12.2	7.7
Bio-oil	66.5	65.7
Bio-oil composition, wt %, m.f.		
Saccharides	3.3	2.4
Anhydrosugars	6.5	6.8
Aldehydes	10.1	14.0
Furans	0.35	--
Ketones	1.24	1.4
Alcohols	2.0	1.2
Carboxylic acids	11.0	8.5
Water-Soluble – Total Above	34.5	34.3
Pyrolytic Lignin	20.6	16.2
Unaccounted fraction	11.4	15.2

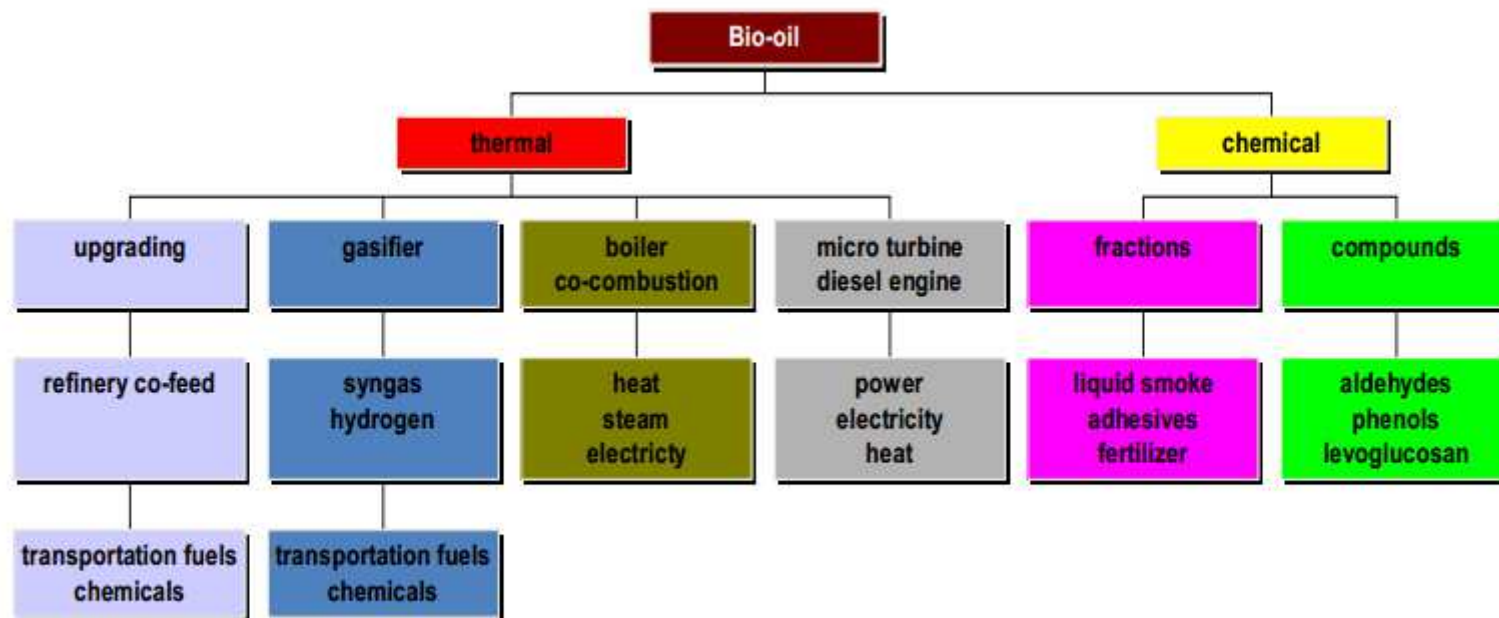
Fast pyrolysis

- Bio-oil applications



Fast pyrolysis

- Bio-oil production through fast pyrolysis can be the heart of the thermochemical conversion based **biorefinery**
- Covalorisation of the resulting char creates economic opportunities for low-cost char production

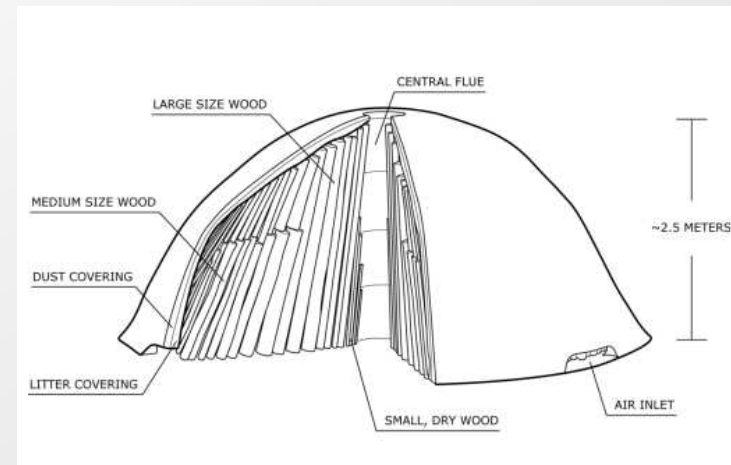
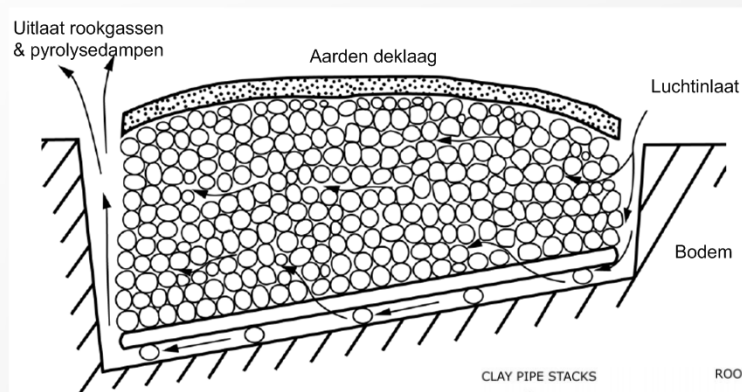


Dietrich Meier, 2008

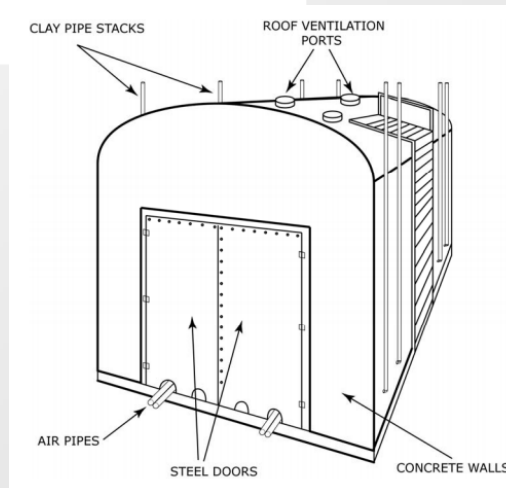
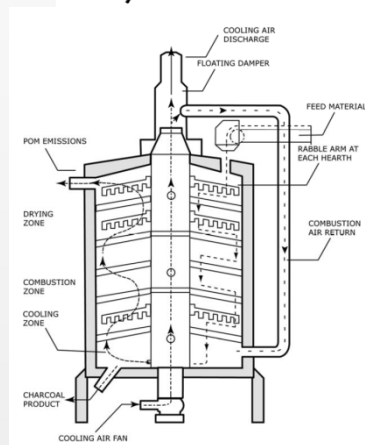
Slow pyrolysis and carbonisation

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- Traditional application in charcoal production: intention is to produce a smokeless fuel (annual production of 45 Mton)
- Could be applied for biochar production
- i.e. pits & mounds, kilns (steel, brick), retorts...



Source: R.C. Brown - ISU



Slow pyrolysis and carbonisation

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- Traditional charcoal production: However...

Type	Char yield (%)
Pit	12.5 – 30
Mound	2 – 42
Kiln, brick walled	12.5 - 33
Kiln, steel walled	18.9 – 31.4
Retort, kilns with process control	33

Char yield,

$$\eta = \frac{m_{char}}{m_{bio}} 100\%$$

	CO (g/kg)	CH ₄ (g/kg)	NMHC (g/kg)	TSP (g/kg)
Batch pit, mound	160 – 179	44 – 57	7 - 60	197 - 598
Kilns, with process control	24 – 27	6.6 – 8.6	1 - 9	27 - 89
Continuous retorts	8.0 – 8.9	2.2 – 2.9	0.4 – 3.0	9.1 - 30

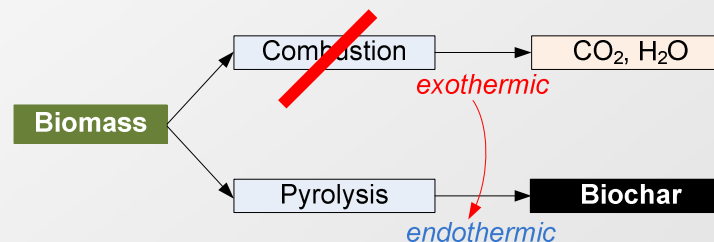
Remark:

NMHC = *non-methane hydrocarbons*

TSP = *total suspended solids*

Slow pyrolysis and carbonisation

- State-of-the-art production biochar,
 - Traditional charcoal production techniques are **polluting**, and **energetically not efficient**
- State-of-the-art production of biochar should address:
 - **Continuous** production: improved energy efficiency and emission control
 - **No** use of **oxygen**: higher biochar yields



- **Recovery and valorisation** of **coproducts**: improved economics
- **Control** of pyrolysis process as a function of the desired physicochemical properties of the pyrolysis products (i.e. char/oil)
- **Feedstock flexibility**: not only wood, but also agricultural and biorefinery residues

Slow pyrolysis and carbonisation

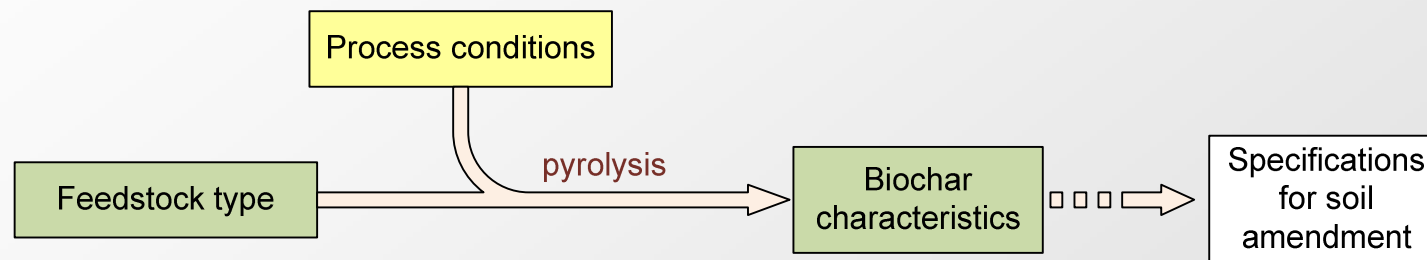
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- State-of-the-art production of biochar, possibilities:
 - 1. Rotating drum reactors (slow pyrolysis)
 - 2. Auger reactors (slow or fast pyrolysis)
 - 3. 'Flash carbonizer' (trage pyrolysis)
 - 4. Fluid bed reactors (fast pyrolysis)
 - 5. Gasifiers (fixed or fluid bed)
 - 6. Hydrothermal systems

Slow pyrolysis and carbonisation

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- A wide matrix of processing technologies, a wide range of feedstocks available
 - → Effect on the resulting biochar ?
- Research aim: (Ronsse *et al.*, 2013) to link,

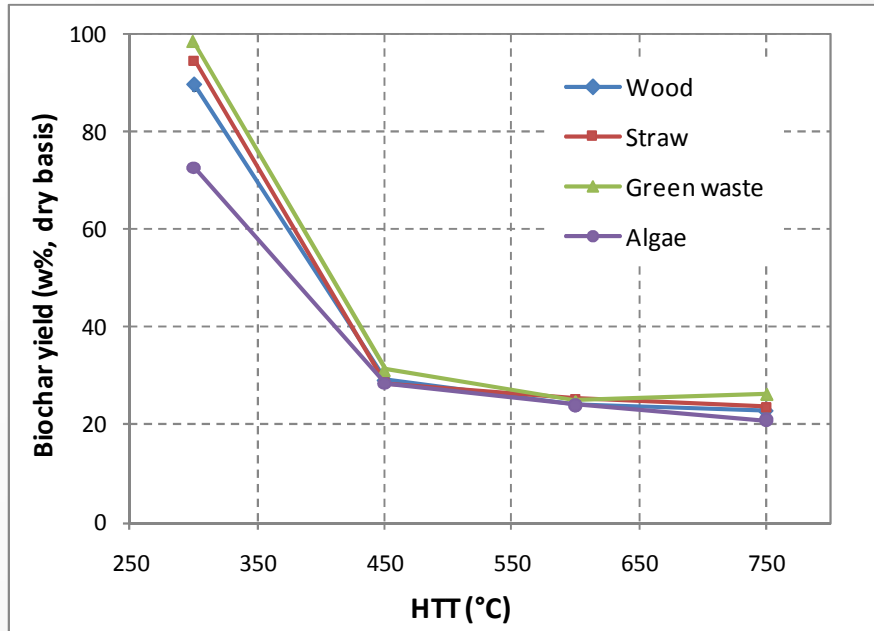


- **Feedstock** types studied: wood, straw, “green waste”, algae
- **Process parameters**: residence time, temperature (defined as HTT)
- **Biochar characteristics**

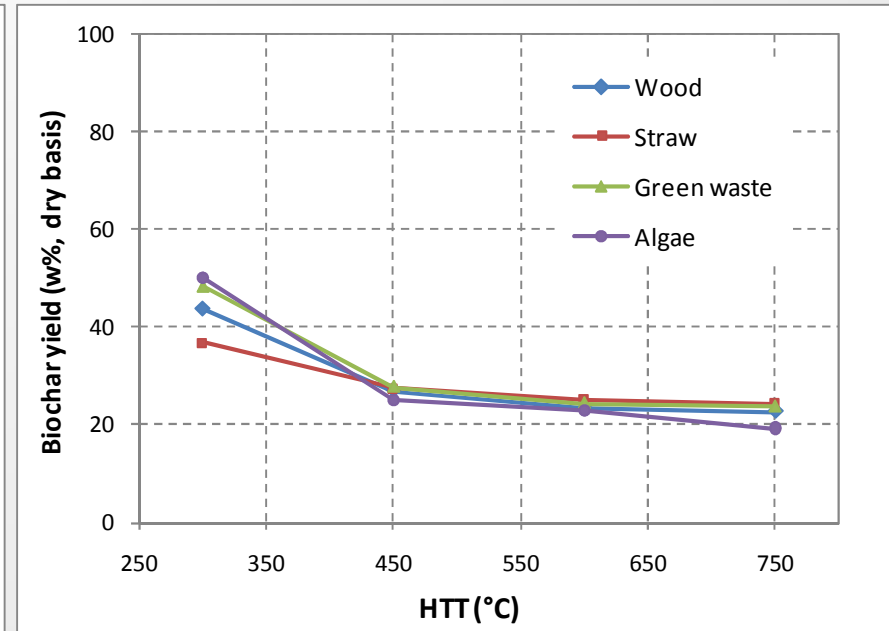
Slow pyrolysis and carbonisation

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- Biochar yield



$t_r = 10$ min.



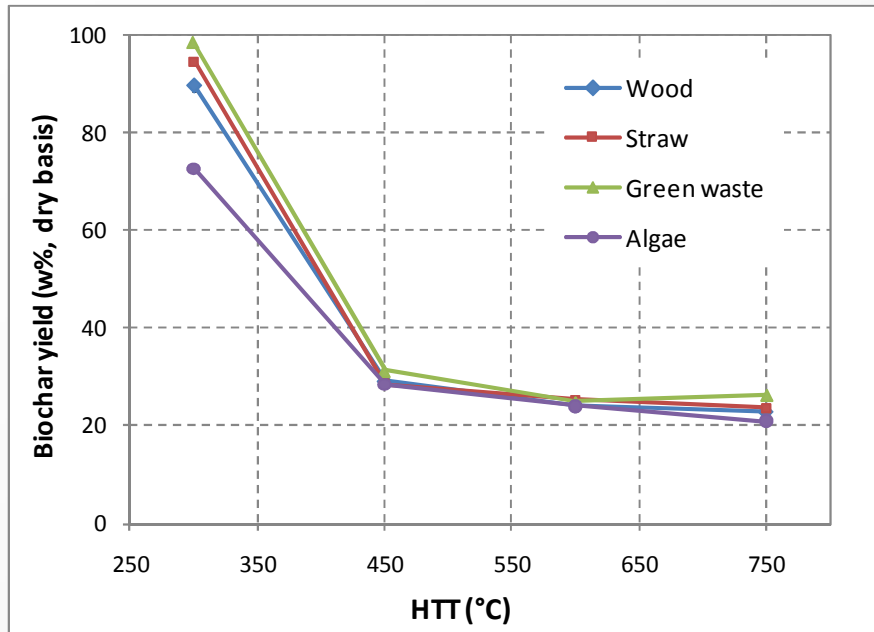
$t_r = 60$ min.

- Effect of feedstock, HTT and t_r
- Generally low yields: large sweep gas flow rate (800 ml/min) → low vapor residence time

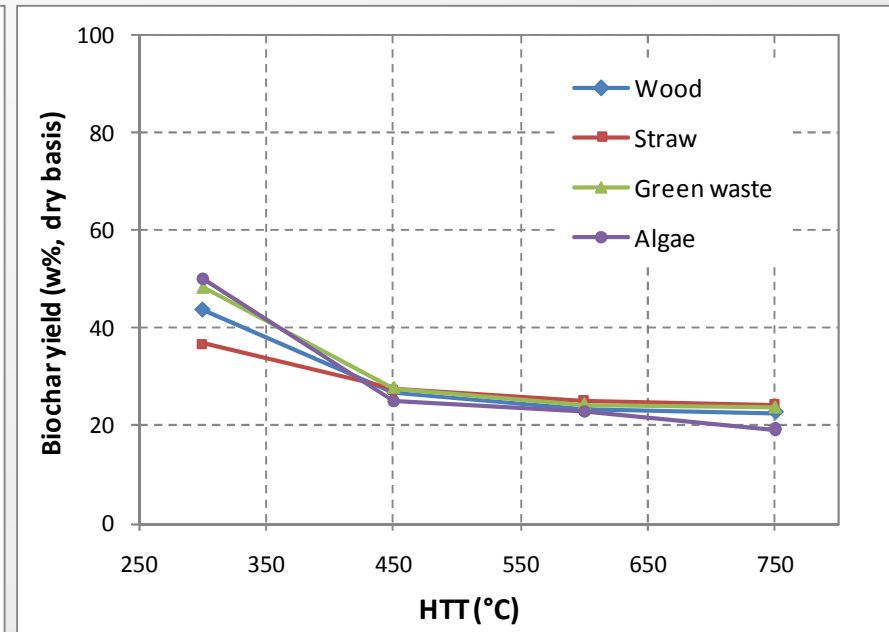
Slow pyrolysis and carbonisation

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- Biochar yield



$t_r = 10$ min.



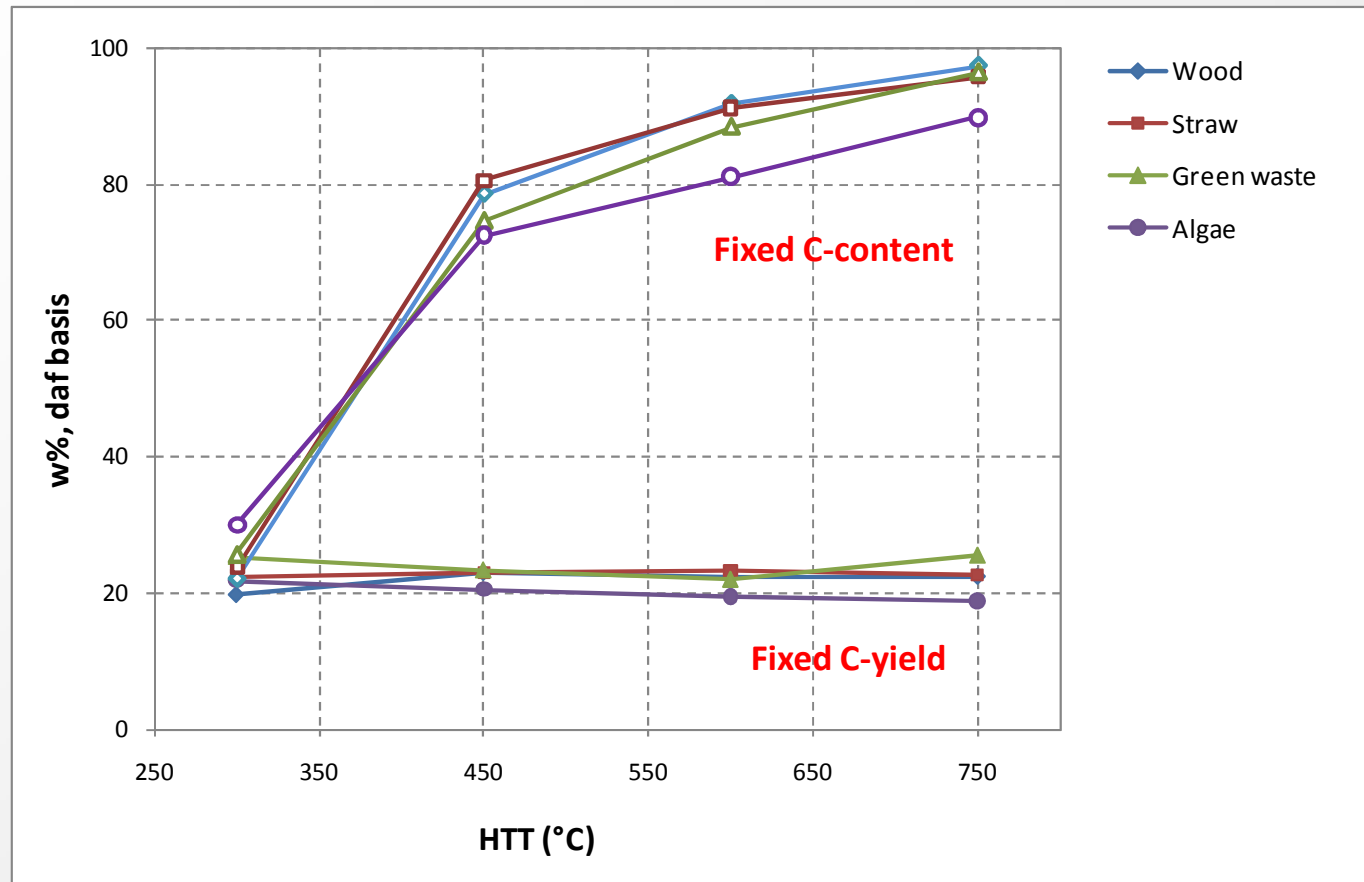
$t_r = 60$ min.

- Green waste: high initial humidity (31.6 w% versus 5.8, 8.0 and 5.3 w% for wood, straw and algae, respectively)
- Algae: high ash content (38.4 w% versus 0.2, 7.9 and 3.5 w% for wood, straw and green waste, respectively)

Slow pyrolysis and carbonisation

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- Proximate analysis

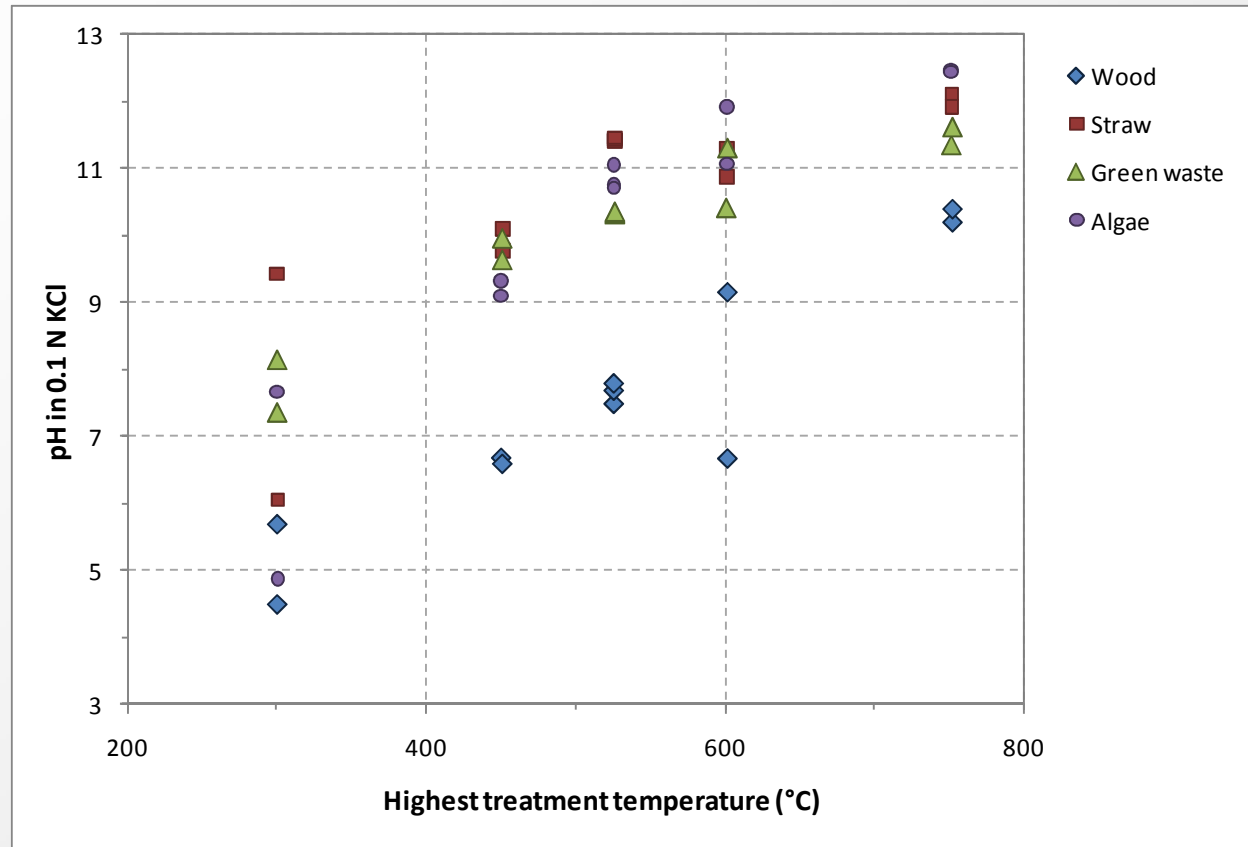


- Fixed C-content $\sim$ HTT, however C-yield (w% daf) was constant $\rightarrow$ **problem of the method to characterize biochar ?**

Slow pyrolysis and carbonisation

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- pH in solution (10 w/v% in 0.1 N KCl)



- More **intense** thermal treatment → **higher** pH
- Wood: generally lower pH than other feedstocks

Slow pyrolysis and carbonisation

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- BET surface area (m²/g)

(a) Wood biochar

Residence time (min)	Highest treatment temperature (°C)			
	300	450	600	750
10	-	4	196	128
60	6	23	127	-

(b) Residence time = 60 min.

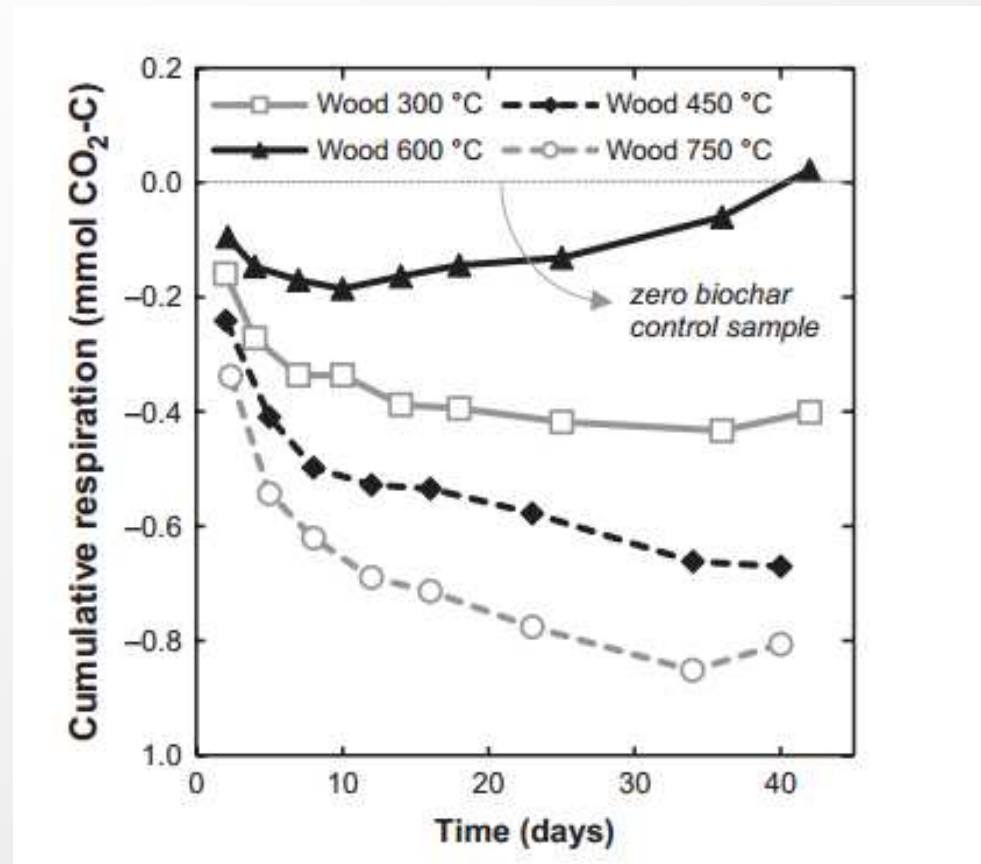
HTT (°C)	Biomass input material			
	Wood	Straw	Green waste	Algae
450	23	16	17	14
600	127	22	46	19

-: No data recorded

- Optimum temperature ($t_r = 10$ min.) – char restructuring or ash melting ?
- BET surface area result of **combined** HTT and t_r effect
- **Ash content** of feedstock negatively correlated with BET surface area (0.2, 7.9, 3.5 and 38.4 w% for wood, straw, green waste and algae, respectively)

Results

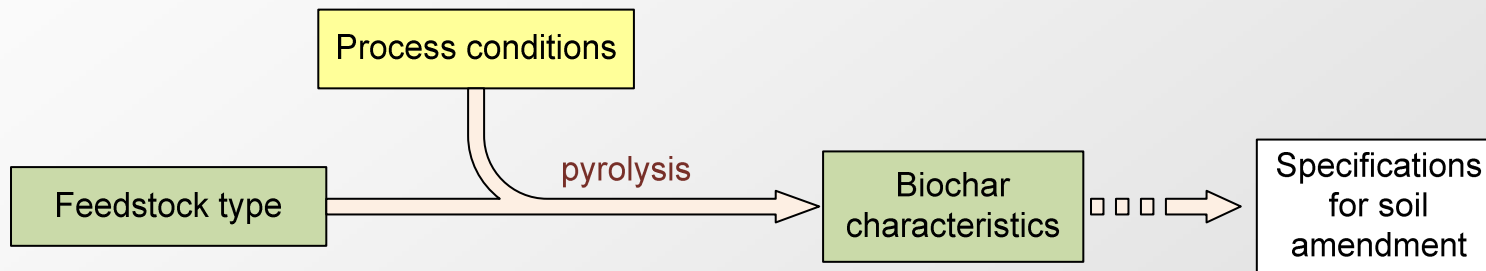
- Biological degradation: soil incubation test



- Initial depression of carbon mineralisation (negative priming effect) ?

Conclusions

- Patterns emerging between physicochemical biochar properties and pyrolysis conditions
- The effect of temperature and residence time
- However, no clear understanding how physicochemical properties relate to 'functional properties' (i.e. soil amendment qualities, stability)



Questions ?

